Effective Information Management in Joint Operations based on Semantic Technologies

Herwig Moser[1], Norbert Oswald[2], Toni Reichelt[3], and Stefan Förster[2]

[1] University of Stuttgart
herwig.moser@ipvs.uni-stuttgart.de
[2] EADS Defence & Security, Military Air Systems
{norbert.oswald,stefan.foerster}@eads.com
[3] Chemnitz University of Technology
toni.reichelt@informatik.tu-chemnitz.de

Abstract. Sharing information between collaborating military assets by using modern information- and communication technologies is a core principle for complex distributed military operations. In this paper we introduce an Information Management System which combines OWL-Ontologies and automated reasoning with Publish/Subscribe-Systems, providing for a shared but decoupled data model. We emphasise the novel application and lack of practical experience of using Semantic Web technologies in areas other than originally intended. That is, aiding decision support and software design in the context of a mission scenario for an unmanned system. Experiments within a complex simulation environment show the immediate benefits of a semantic information-management and -dissemination platform: Clear separation of concerns in code and data model, increased systems re-usability and extensibility as well as simplified integration of external information sources.

1 Introduction

Information technology has made it possible for today's armed forces to interconnect associated entities on and off the battlefield, conducting so called *Network Centric Operations* (*NCOs*).

In this context, information-timeliness, -relevance and -accuracy as well as -distribution is essential. Unfortunately, the immanent information is mostly unstructured, does not reflect a general consensus regarding its meaning and is not available through standardised channels [1, 2]. Hence, information requires a suitable *description* as well as proper mode of *access*.

When we talk about the description of information (i.e., meta-information), we require it to exhibit a structure beyond that of plain lists of symbols, but instead defining relations and thus giving them meaning. To be able to fully gain the benefits of highly structured information in the form of automated reasoning, an unambigous formalism is required, going beyond semi-structured data models like JC3IEDM [3]. Therefore we make use of *ontologies* [4], providing the descriptions and exploit *Description Logic* (*DL*) [5] for the possibility to perform *inferences* over the available information.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **OCT 2009**	2. REPORT TYPE **N/A**	3. DATES COVERED -

4. TITLE AND SUBTITLE **Eective Information Management in Joint Operations based on Semantic Technologies**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of Stuttgart**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES

See also ADB381582. RTO-MP-IST-087 Information Management - Exploitation (Gestion et exploitation des informations). Proceedings of RTO Information Systems Technology Panel (IST) Symposium held in Stockholm, Sweden on 19-20 October 2009., The original document contains color images.

14. ABSTRACT

Sharing information between collaborating military assets by using modern information- and communication technologies is a core principle for complex distributed military operations. In this paper we introduce an Information Management System which combines OWLOntologies and automated reasoning with Publish/Subscribe-Systems, providing for a shared but decoupled data model. We emphasise the novel application and lack of practical experience of using Semantic Web technologies in areas other than originally intended. That is, aiding decision support and software design in the context of a mission scenario for an unmanned system. Experiments within a complex simulation environment show the immediate bene ts of a semantic informationmanagement and -dissemination platform: Clear separation of concerns in code and data model, increased systems re-usability and extensibility as well as simpli ed integration of external information sources.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**8**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

However, ontologies do not solve the problem of how to make information available to all assets. For the highly dynamic environment that NCOs represent, information distribution is most efficiently managed by asychronous event-based communication, as intrinsically provided by *Publish/Subscribe* (*P/S*) [6, 7] systems.

From the combination of both technologies into an *Information Management System* (*IMS*) emerges a synergy which we exploit for efficient information acquistion and distribution in NCO.

2 System Architecture

We developed an IMS consisting of a P/S mediator with integrated *Web Ontology Language* (*OWL*) [8] *Knowledge Base* (*KB*) and reasoner which can be employed in various NCO-participating platforms. Following the idea of having network-centric capabilities, publishers and subscribers are providers and consumers of relevant mission-specific information, contributing to the information superiority on a platform. Providers and consumers can be internal to the platform or represent external participants.

Internally, the P/S mediator stores incoming information in its KB and uses the reasoner to draw conclusions from the combination of existing and newly published information. Registered subscriptions are evaluated against asserted and inferred information and trigger a notification if a match is found. The reasoner thus provides a form of indirection in the matching process, by making implicit information explicit, decoupling publisher and subscriber on the level of the data model (see [9] for details). That is, subscriptions may, but need not, explicitly match the type of publication. *Concept Decoupling* is what we refer to when that match is found through *implicit* type equivalence of publication and subscription.

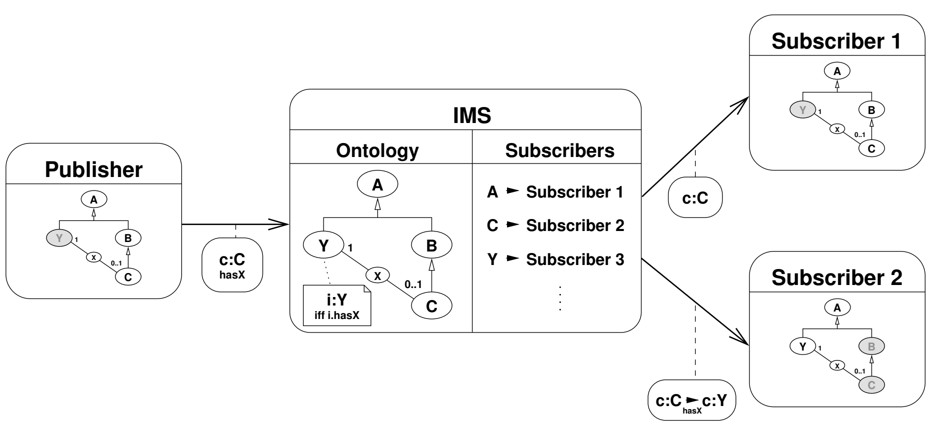

Fig. 1: The information flow through the IMS based on concept decoupling.

Figure 1 shows how an information provider and two subscribers publish respectively receive information, represented using OWL statements, mediated by the IMS. An explicit match takes place for Subscriber 1, where the type of publication (C) equals that of the subscription. Additionally, the notification of Subscriber 2 results from logical deduction, because the reasoner found the subscription's type Y to also be a valid match.

2.1 IMS Interface

The IMS' interface reflects the basic operations required to fulfill the roles of a P/S mediator. Figure 2 shows how the components of our P/S system interact, highlighting the semantics of the interfaces:

- Publish: This interface accepts documents containing semantically annotated data, representing information to be changed or added to the KB.
- Subscribe: Documents sent to this interface represent subscriptions.
- Notify: Subscribers are required to provide a notification interface, allowing call-backs upon subscription related events.
- Query: The Query interface can be invoked with the documents of the same format as subscriptions, returning all matching contents immediately.

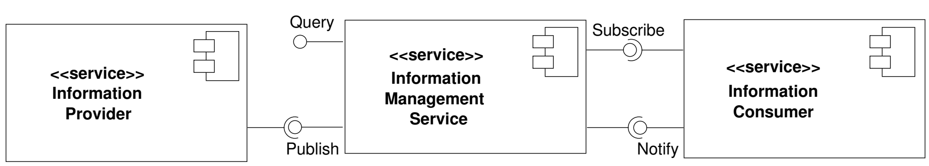

Fig. 2: UML2 component relationships of the IMS and client services.

3 Demonstration

To demonstrate our IMS to be effective, we have chosen a joint mission, consisting of, but not limited to, an unmanned platform, its ground station and ground-based armed forces, in a simulated environment. Despite its demonstrative nature, the IMS implementation currently achieves *Technology Readiness Level* (*TRL*) 5 [10]. When equipped with an IMS, platforms may benefit from reciprocal information flow between them and other platforms. To show the mechanism in detail we now describe the IMS-based data-flow within a section of a mission system of an *Unmanned Air Vehicle* (*UAV*) performing, in our case, a reconaissance mission.

3.1 Mission Ontology

Figure 3 shows an excerpt of the mission ontology which represents the shared data model used by all participating assets, based on the IEEE SUMO [11]. Significant for the mission execution is the formalisation of an ObstacleObject. Its definition is that of a PhysicalObject which crosses the current Flightplan. Hence, publications of entities describing physical objects, such as SAM sites, may, if they have the additional property of obstructing the flightpath, trigger a notification to subscribers interested in obstacles.

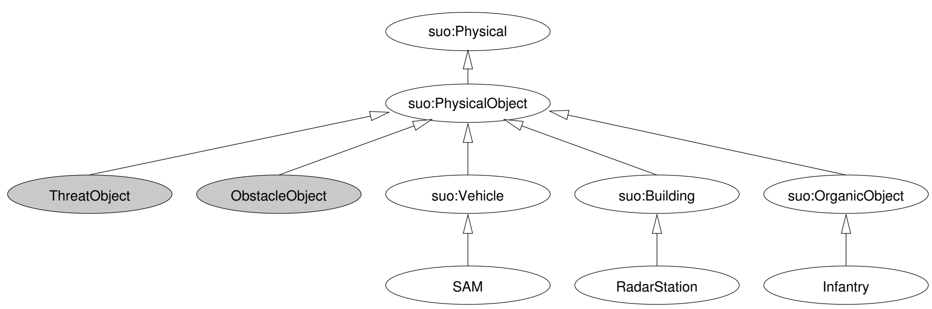

Fig. 3: An excerpt of the ontology hierarchy, with a focus on Vehicle concepts.

3.2 Inter- and Intra-System Dataflow

Figure 4 deptics the dataflow between mission participants and internal components of the P/S system. The UAV acquires information from its own sensors (here, a *Radar Warning Receiver* (*RWR*)) as well as from its ground station. One of its objectives is to avoid flying across hostile units, some of which it is not able to detect itself. The functionality of obstacle avoidance, in our case represented by the *Situational Awareness* (*SA*) component, is universally applicable in that it only needs to know the location and range of the object to circumvent.

Concept decoupling fosters this type of functionality encapsulation. It allows subscribers to request to be only notified of publications that either match directly or indirectly. Implicit matches do not require the need for a subscriber to have a priori knowledge of what information may be inferred to match at some future point. Notice in Figure 4 how none of the information sources publish any form of Obstacle and yet the SA component will get notified if the reasoner determines a match such that some other publication is classified to be an Obstacle.

3.3 Mission Execution

As depicted by Figure 5, the UAV (✉) is given an initial flightplan and has knowledge of a hostile SAM site (⬘). As the UAV proceeds to the mission area,

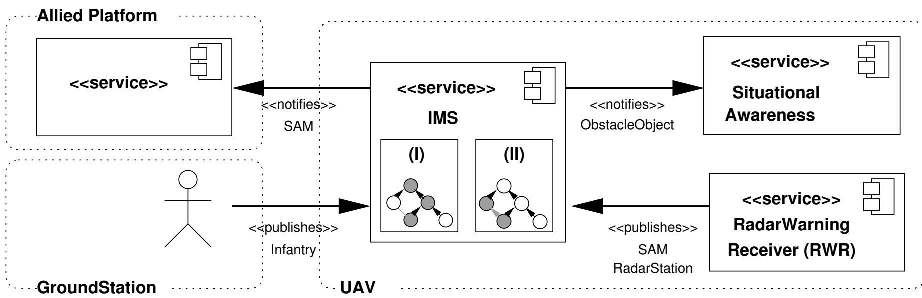

Fig. 4: Information flow mediated by the IMS.

its RWR receives signals from a previously unknown radar station (◆). Publishing its findings, the IMS concludes, based on inference rules, that the radar station is to be considered as an obstacle because of its location directly on the flightpath. As Figure 4 shows, a Situation Awareness service is notified of obstacles and triggers avoidance functionality. As the UAV reaches the second segment of its flight plan, the GroundStation operator informs the UAV of hostile infantry in the area (❖). Again, the IMS infers an obstacle match and the SA service is notifed. Having avoided the hostile infantry unit, the RWR again picks up signals, this time from a hostile SAM site (⬘). This finding produces two matches, one by the ObstacleObject subscription of the SA service and the other by a subscription of some Allied Platform, interested only in SAM sites. Both subscriptions are satisfied, although producing different types of notifications. The external subscriber thus gains knowledge of a hostile SAM site, potentially outside its own range of perception.

4 Conclusions

Even though the use of semantic technologies has already gained much attention in the development of web applications, their use in the military domain have only been studied to a very limited extent.

In this paper we have presented the Information Management System, an extended Publish/Subscribe mediator based on semantic technologies. The use of Description Logic ontologies, the basis for the OWL, has the advantage of unambiguous formal semantics and associated automated reasoning. The combination of asynchronous mediated data distribution and integrated reasoning yields an efficient way of managing information in joint operations. Through the additional level of decoupling introduced on the data model level by semantic matchmaking, entities exchanging information based on the IMS exhibit a higher degree of functional locality.

For the demonstration on how this principle can be applied in practise, we have created a joint mission scenario in a simulated environment where the participating assets reciprocate, using the IMS, to enhance their respective local

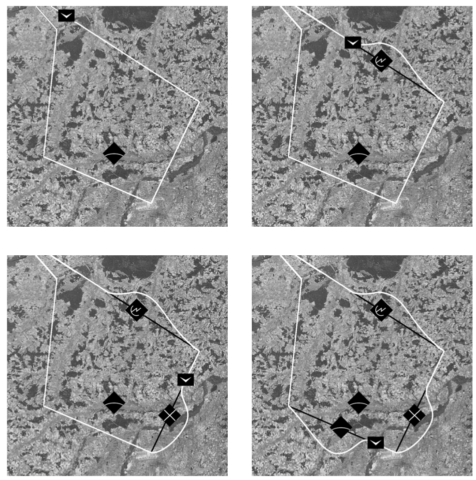

Fig. 5: Stages of the UAV's mission execution.

operational picture. We emphasise the high level of technology readiness already achieved with respect to the limited experience with semantic technologies in military applications.

References

1. Board, D.S.: Information management for net-centric operations. Technical report, Department of Defense (2006)
2. Wunder, M.: The benefit of ontologies for interoperability of ccis. In: 8th International Command and Control Research and Technology Symposium, Washington DC, USA (2003)
3. Programme, N.M.I.: The joint c3 information exchange data model overview. http://www.mip-site.org/publicsite/04-Baseline_3.0/JC3IEDM-Joint_C3_Information_Exchange_Data_Model/JC3IEDM-Overview-UK-DMWG_Edition_3.1a_2007-02-16.pdf, [Last accessed 11.12.2007] (February 2007)
4. Gruber, T.: Toward principles for the design of ontologies used for knowledge sharing. International Journal Human-Computer Studies **43**(5-6) (1995) 907–928
5. Baader, F., Calvanese, D., McGuinness, D., Nardi, D., Patel-Schneider, P., eds.: The Description Logic Handbook. 2nd edn. Cambridge University Press (2007)
6. Xiong, M., Parsons, J., Edmondson, J., Nguyen, H., Schmidt, D.: Evaluating technologies for tactical information management in net-centric systems. In Suresh, R., ed.: Defense Transformation and Net-Centric Systems 2007. Volume 6578., Bellingham, USA, SPIE–The International Society for Optical Engineering (2007) 65780A
7. Perry, M., Delporte, C., Demi, F., Ghosh, A., Luong, M.: Mqseries publish/subscribe applications. Technical report, IBM (2001)
8. Patel-Schneider, P.F., Hayes, P., Horrocks, I.: Owl web ontology language semantics and abstract syntax. http://www.w3.org/TR/2004/REC-owl-semantics-20040210/ (February 2004)

9. Moser, H., Reichelt, T., Oswald, N., Förster, S.: Information management for unmanned systems: Combining DL-reasoning with publish/subscribe. In: Proc. of SGAI 2008, Springer (2008)
10. Mankins, J.C.: Technology readiness levels. NASA Whitepaper (April 1995)
11. IEEE: Suggested upper merged ontology. URL, `http://suo.ieee.org/SUO/SUMO/index.html` (October 2007)